Manipulating the Toughness of Rocks through Electric Potentials

Completed Technology Project (2011 - 2012)

Project Introduction

When rocks are stressed, electronic charge carriers are activated which are defect electrons in the oxygen anion sublattice, O− in a matrix of O2−, known as positive holes. They have properties such as the ability to flow out of the stressed volume and spread into the surrounding unstressed rocks. The wave function associated with these charge carriers is highly delocalized, meaning that the spin density is distributed over hundreds of O2− neighbors.

We conducted three sets of experiments to test the prediction that a specific quantum mechanical effect, the delocalization of the electronic wave functions associated with oxygen anions in the 1− valence state, has a measurable effect on fundamental properties of rocks. Normally the O− exist in the structure of rock-forming minerals in the form of tightly bonded O−pairs, called peroxy defects. We set out to measure (i) the “softening” of rocks in which peroxy defects are activated, (ii) our capability to manipulate the distribution of the electronic charge carriers, called positive holes, that arise from the delocalized O− states, and (iii) the volume expansion predicted to accompany the break-up of peroxy bonds and delocalization of the wave functions. We successfully demonstrated (i) and (ii), showing a “softening” of the rocks on the order of 10-15%. We did not yet successfully demonstrate the volume increase effect.

The mechanical properties of materials, including rocks, are influenced by many factors. Most prominent among those factors are defects on different scales. They range from point defects on the scale of atoms to linear defects within grains such as dislocations, 2-dimensional defects along grain boundaries, and larger defects such as microfractures. The many forms of imperfections can be summed up as “damage”. Damage is usually accumulative but can often be “repaired” through various annealing processes. In this project we have pursued a particular form of imperfections due to point defects in the oxygen sublattice of minerals, whereby oxygen anions have changed their valence from the usual 2− state to 1−. Under certain conditions point defects that consist of pairs of O− become activated. As the O−−O− bond breaks up, there is strong evidence that the wave functions associated with the O− become delocalized over many neighboring oxygen anion position. As we show in this Report this quantum mechanical process of delocalization has a measurable effect on the mechanical properties of rocks: it makes rocks mechanically weaker and softer.

Anticipated Benefits

This quantum-mechanical effect was needed to explain a striking anomaly in the thermal expansion of MgO 3. Our early work led to two predictions that are of NASA interest in the context of Earth and Planetary Sciences and earthquake hazard prevention: (i) emission of non-thermal infrared photons from the surface 4,5 (ii) change in radar reflectivity of the surface due to the arrival of positive hole charge carriers at the surface 6. This is particularly

Photo of the historically first experiment where a long slab of rock, here gray granite, was stressed at one end and the self?generated currents was drawn out of the other, unstressed end.

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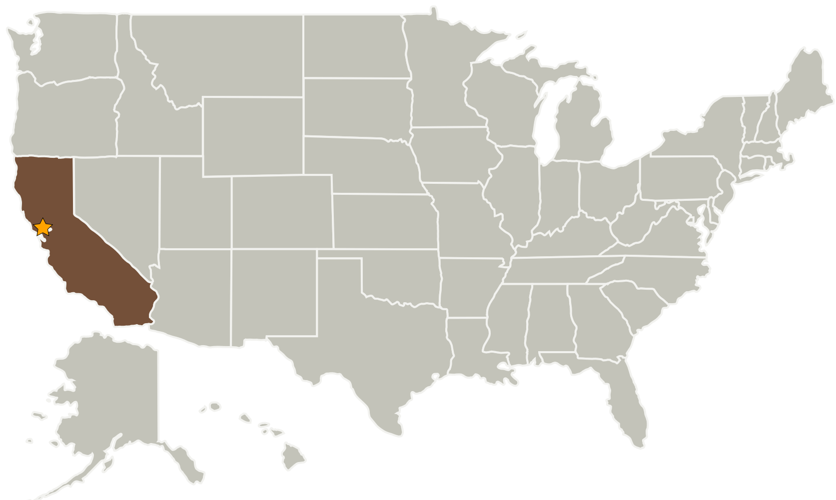
relevant to Mars exploration and Earth observation.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Ames Research Center(ARC)	Lead Organization	NASA Center	Moffett Field, California
Blekinge Institute of Technology(BTH)	Supporting Organization	Academia	Karlshamn, Outside the United States, Sweden
Lomonosov Moscow State University	Supporting Organization	Academia	
San Jose State University	Supporting Organization	Academia	San Jose, California
University of California-Santa Cruz	Supporting Organization	Academia	Santa Cruz, California

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Ames Research Center (ARC)

Responsible Program:

Center Innovation Fund: ARC CIF

Project Management

Program Director:

Michael R Lapointe

Program Manager:

Harry Partridge

Project Manager:

Minoru M Freund

Principal Investigator:

Minoru M Freund

Co-Investigators:

Ramen Bahuguna
Peter Beyersdorf
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Parul Agrawal
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Friedemann T Freund
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Claes Hedberg

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Primary U.S. Work Locations
California

Images

Stressed Granite Slab
Photo of the historically first experiment where a long slab of rock, here gray granite, was stressed at one end and the self? generated currents was drawn out of the other, unstressed end.
(https://techport.nasa.gov/image/5003)

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**

1 2 3 4 5 6 7 8 9

Applied Research | Development | Demo & Test

Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  └ TX12.3 Mechanical Systems
    └ TX12.3.6 Mechanical Drive Systems